4. IMPLEMENTABILITY STUDIES

4.1 Introduction/Background

The implementability testing was conducted at the Applied Geotechnical Engineering and Construction test site in Richland, Washington, April 16-24, 2001. The full-scale implementability testing was designed to demonstrate the injectability of those grout formulations recommended from the bench testing. This testing provides essential information concerning the operational aspects and column development properties of chosen grout materials such that a down selection from three grouts recommended from the bench testing to one grout for field testing was possible. The three grouts that were chosen (see section 3.11) include GMENT-12, U.S. Grout Premium Grade, and TECT HG.

4.2 Objectives

The main objective of the implementability testing was to down-select a single grout from the three grouts chosen from the Bench testing discussed in the preceding chapter. In addition, data useful for the Field testing include those objectives listed in the test plan (Grant et al. 2000):

4.2.1 Test Objective 8

This objective is to evaluate the Field Implementability of the Grout Emplacement Process for Monolith Design and Application.

Information relative to the functionality of hardware designs, safety equipment, grouting procedures, materials mixing, and delivery logistics will be collected during grout emplacement for the full-scale implementability tests. A combination of qualitative and quantitative data will be collected during and after grouting. A detailed examination of the grouted waste forms will also be performed to evaluate the quality and integrity of the grout and grout–soil columns verified by destructive examination.

4.2.2 Noncritical Test Objective C

This objective is to evaluate the Volume, Type and Expected Disposition of Secondary Waste.

A quantitative analysis will determine the total volume and type of secondary waste generated as a result of the grouting process. The secondary waste determination will be used to group each type of waste according to disposal options for use in future in situ grouting operations.

Results of the applicability assessment will improve the estimates of cost and implementability associated with in situ grouting processing of buried waste at the SDA for the Operable Unit 7-13/14 Remedial Investigation/Feasibility Study.

The secondary waste determination will be used to estimate the total volume of secondary waste that may be expected during actual full-scale remediation of the SDA using in situ grouting. The estimate will be included in the applicability analysis section of the final report on the in situ grouting treatability study.

4.3 Test Hardware Description, Procedures

4.3.1 Hardware

The hardware consisted of water supply tanks, two in-series vortex mixers, and associated supply pumps, a JET 5 CASA GRANDE high-pressure injection pump, high-pressure injection lines, a CASA GRANDE C-6 rotopercussion drill jet grouting system, a typical mud balance, and the special thrust blocks discussed separately in this section. Figures 8, 9, and 10 show the Vortex mixer, high-pressure pump, and grout drilling rig set up on a thrust block, respectively.

Figure 8. In-line vortex mixers.

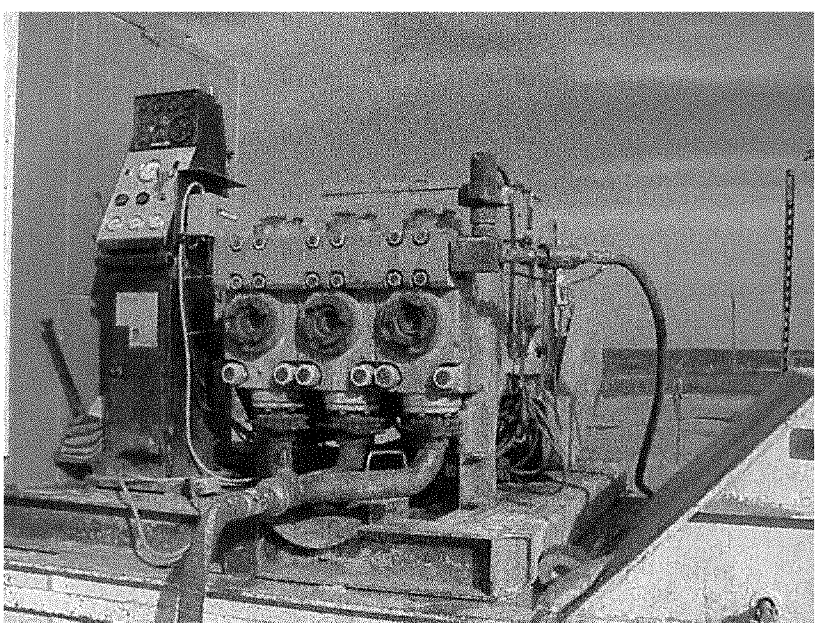

Figure 9. High-pressure pump.

Figure 10. CASA GRANDE C-6 drill system on thrust block.

To measure grout flow, two in-line high-pressure flow meters were used, one a Jean Lutz-LT3n, C16M-B74, SP100MC21 pressure/volumetric flow device that measures the number of strokes of the positive displacement pump, and the other an in-line Halliburton turbine meter (Figures 11–12 show these devices).

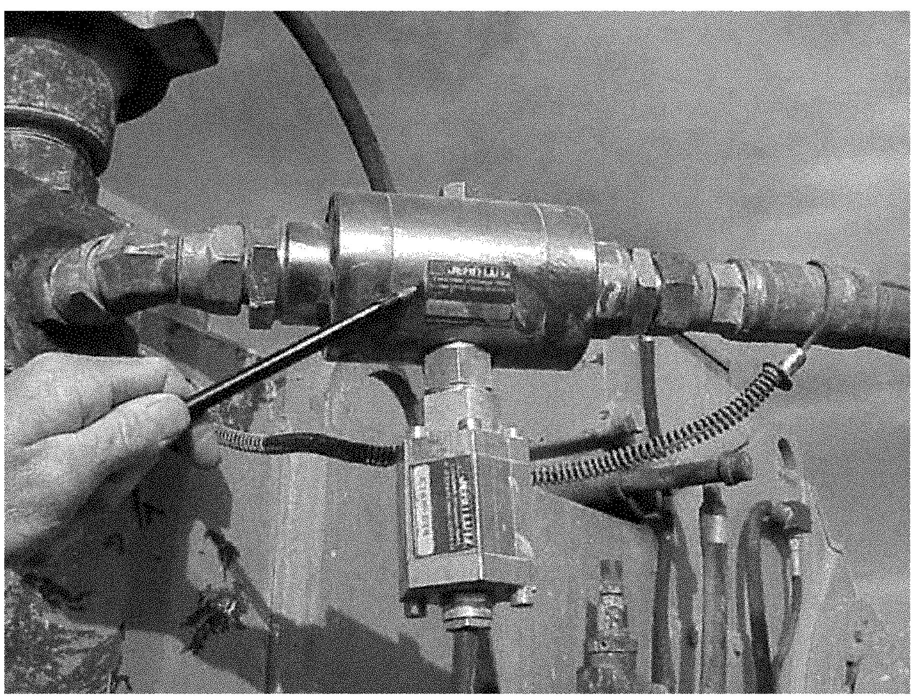

Figure 11. Jean Lutz pressure/flow meter.

Figure 12. Halliburton in-line flow meter.

When comparing data from the two flow measuring devices the integrated volumetric flow agreed with each other within 14%. In all cases, the Jean Lutz system measured about 14% lower than the Halliburton system. It is noted that the Jean Lutz system was purchased specifically for this test and was calibrated prior to testing by a factory representative and therefore is thought to be the most accurate. The Halliburton meter was used in previous INEEL testing (Loomis 1996) and the measured volume of grout that went into a pit was high relative to the amount of void volume in the pit. It was speculated in that work that the discrepancy was a water calibrated volumetric flow device erroneously measured the grout flow too high. However, the fact that the two systems agreed for a variety of grout types suggests that the Halliburton system was calibrated correctly in the past study in that for the present work it also was calibrated using water only.

4.3.2 Procedures

The implementability testing involved the following steps:

Construction of Site/Initial Testing

Initial preparation tasks included construction of a test area similar to disturbed soil conditions expected at the SDA. A pit 6.6 m (21 ft) long was excavated 1.2 m (4 ft) wide by 3.3 m (11 ft) deep and backfilled with equivalent INEEL-RWMC-type silty-clay soil obtained from a site near Benton Washington. Representativeness was verified by comparative soil composition tests. The backfilling was a loose pack without machine packing—the intent being to create a site with 30-50% by volume free voids. Next, three specially prepared mock-up thrust blocks were arranged over the pit as shown in Figure 13.

Figure 13. Thrust blocks in place on top of pit (without side berming).

The thrust block with three holes on a 50 cm (20-in) triangular pitch was designed to catch excess grout returns to the surface during grouting. The thrust blocks were lined with Styrofoam to prevent grout returns from sticking to the surfaces of the thrust block and the access holes for grouting were lined with brushes to provide wiping of the drill steel during withdrawal of the drill stem. The void space under the thrust block was 0.45 m3 (16 cu. ft) which allows 449 L (119 gal) of returns for each block. Prior to grouting the three grouts, a nozzle optimization study was performed for those grouts that had never been field grouted before: GMENT-12 and U.S. Grout Premium Grade. In these nozzle studies each grout was tested with a 2.4-mm and a 3-mm nozzle by jet grouting 1.2 m (4 ft) high columns in a specially prepared RWMC-INEEL type soil region. The columns were allowed to cure overnight and then a trench was created adjacent to the columns and the columns were exposed, examined and photographed. Eventually, the columns were removed intact and broken in two pieces using a standard backhoe. The nozzle size that allowed jet grouting at 400 bar (6,000 psi) to create the largest column was chosen for the implementability testing involving the thrust blocks.

Implementability Grouting

- Samples of each grout batch were collected directly from the mixer before grouting was initiated and tested for density using an industry standard mud balance.

- The jet-grouting rig was positioned for grouting of the field trials. Basic procedures established during the Acid Pit Stabilization Treatability Study (Loomis et al. 1999) were followed. Grouting was performed with the following parameters: two revolutions per step, a step distance of 5 cm (1.97 in.) per step and a step rate dependent on the results of either the special a nozzle test or based on an attempt to place the identical amount of grout in each triplex of columns. Injection pressure was nominally 400 bar (6,000 psi). The basic injection process was as follows:

- Position jet-grouting apparatus drill string over a hole in a thrust block
- Drill to 3.6 m (11.91 ft) below the top surface of the thrust block (includes the thickness of the thrust block-15 cm (6 in.), space under the thrust block –30 cm (12 in.), 73 cm (29 in.) of overburden, and 2.4 m (8 ft) of grout column)
- Commence high-pressure injection and retract rotating drill stem 8 ft
- Discontinue high-pressure pumping
- Raise drill stem (allow grout to drain)
- Move to next hole and repeat the procedure
- Place the thermocouple assembly down one hole in each thrust block following grouting
- Place the 7 cm (2.75 ft) outside diameter by 5.1 m (17 ft) long polyethylene rod in one hole of the nine holes (At random, it was determined during testing to use the TECT HG test area.).

One three-column monolith was attempted for each grout. Figure 14 shows the layout of the thrust block with basic dimensions for the various features. Three grout types recommended from the bench testing made for a total of nine grout holes. Qualitative and quantitative data gathered during implementability testing included:

Qualitative Data

- Filter caking properties of the material
- Mixing problems such as excessive air entrainment, suspended solids, and material separation
- Equipment fouling and residual buildup inside pumping equipment
- Cracking of soil and heave outside of the thrust block
- Incomplete curing of grout columns
- Qualitative size distribution of soil inclusions in the columns
- Photographic record of the column excavation
- Relative ease of cleanout
- Sticking of grout returns to thrust block
- Durability of brushes on holes
- Other unusual operation occurrences
- Pressure required to remove the 7 cm (2.75-in.) polyethylene rod placed in a grout hole for one of the grout holes (the rods are to be used during field testing to create holes for hydraulic conductivity testing during the field tests).

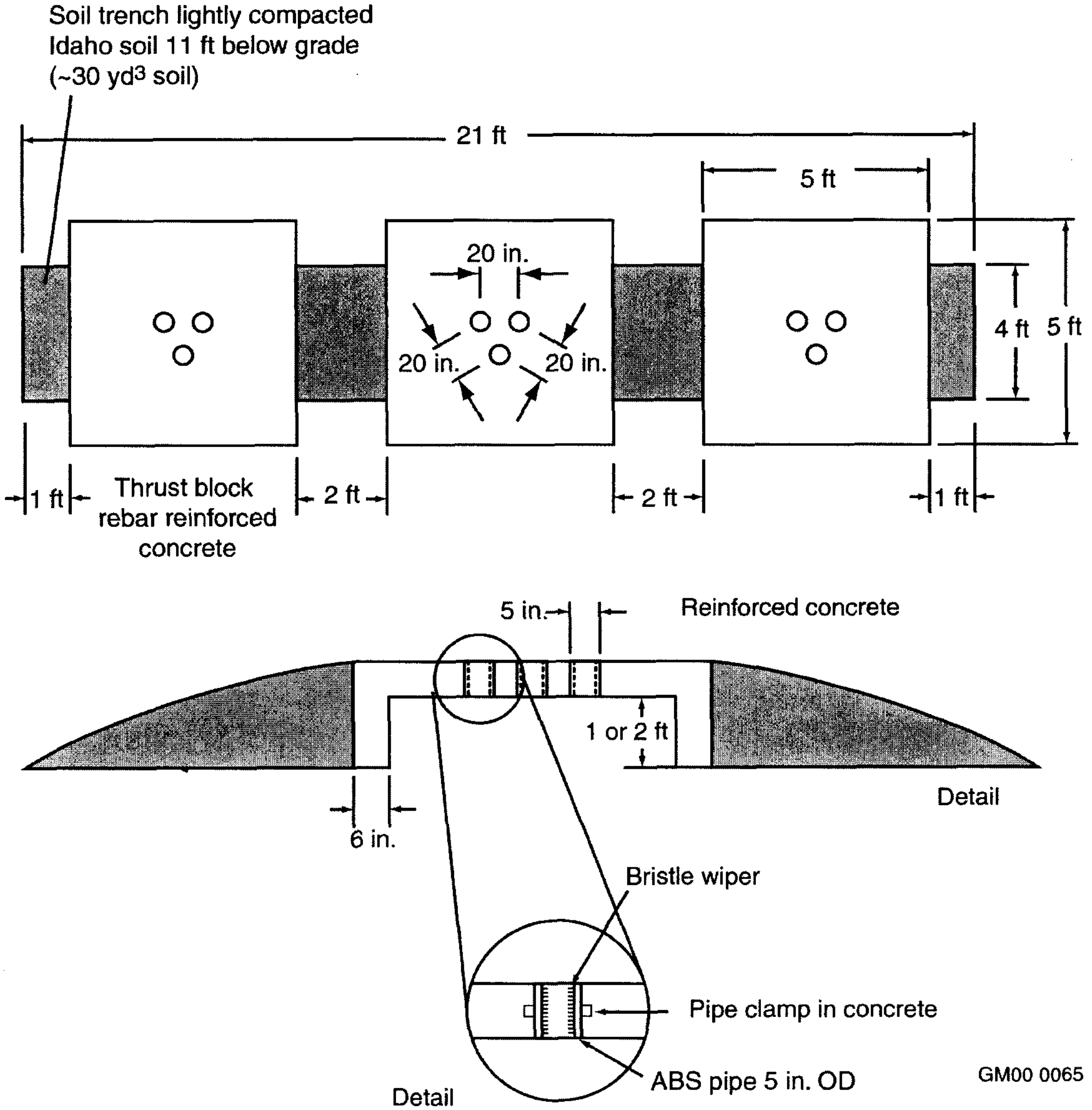

Figure 14. Implementability test layout.

Quantitative Data

- Grout Returns. Grout returns were measured by pumping a slurry mixture of bentonite and water into the thrust block void and subtracting the amount of water pumped from the measured inside volume of the thrust block. When the thrust blocks were removed, the amount of grout returns under the thrust block was also observed and compared to the water pumping method.

- Curing Temperature Curve. Temperature sensors were placed in one grouted hole for each grout type immediately after grouting operations were complete. A portable data logger was attached to the temperature sensors and used to measure and record the temperature of curing at intervals of approximately 20 minutes for the 5-day curing period.

- Amount of Grout Injected and Injection Parameters. The total amount of grout injected for each hole was recorded and the pressure, step size, rotation rate, and time on a step was also recorded.

- Column development measured to ± 1inch using a tape measure.

Following a 1-day set, the thrust blocks were tested for volume remaining under the blocks using the bentonite/water slurry mix. Then, following a 5-day set, the monolith was exposed for examination. Following the cure time, the polyethylene rod was first removed using a standard backhoe and rigging then, the thrust blocks were removed. Following these preliminary tests, the grout columns were excavated using a combination of machine excavation and manual removal of surrounding soil. The first step after removing the thrust block and observing the amount of cured grout returns under the block was to remove the 73 cm (29 in.) of overburden material over the entire area of the columns. Next, directly in front of the row of columns, but not cutting into the columns, a separate trench 2.4 m (8 ft) below grade was cut. This trench was shaped for safe manned entry to further excavate the columns head on by hand. Once excavated, a combination of backhoes and laborers were used to cut surrounding soil away from the columns using hand held picks, crowbars, and shovels. Figure 15 shows a side view of the excavation method. A photographic record was kept and the physical condition of the columns was described. Once excavated and photographed, the columns were pulled down in one piece and isolated for further photographs and evaluation.

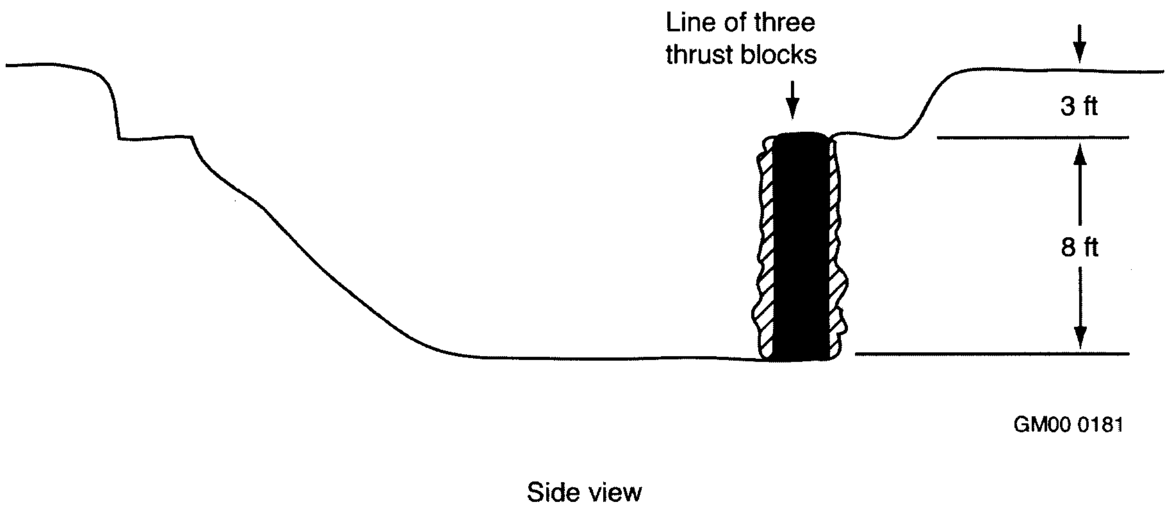

Figure 15. Side view of excavation of implementability tests.

One grout material was selected from among the three grouts used in this study for the field-testing. The grouts were evaluated using engineering judgment using the following criteria as a guide:

- Pumpable with minimal operational problems
- Ease of Mixing
- Optimal column development (a combination of maximum column diameter with low percentage of soil inclusions)
- Minimal grout return
- Cost and availability of grout.

4.4 Results of Implementability Testing

The results include (a) data from a special nozzle test to determine the optimum nozzle to allow jet grouting for those grouts that have never been jet grouted before, (b) grouting results when creating an interconnected three hole monolith under the thrust block for the three grouts, (c) results of curing temperature of the monoliths, (d) results related to placement and removal of the 7 cm (2.75-in.) polyethylene rods to be used as hydraulic conductivity holes, (e) results of quantitative determination of the volume of grout returns, (f) qualitative description and photographic record of the resultant monolith and finally, a discussion of results section in which the three grouts are compared and contrasted and a final single grout is recommended for field testing.

4.4.1 Special Nozzle Testing for U.S. Grout and GMENT-12

Prior to conducting the grouting tests with the thrust block, special nozzle optimization tests were performed to determine an appropriate nozzle for the two new grouts (GMENT-12 and U.S. Grout). The TECT HG had been grouted in prior studies (Loomis 1996, 1998) and a 3-mm nozzle was recommended. The nozzle tests involved creating (in INEEL-like soils) 4 ft high columns at a depth of 3 ft below grade. An attempt was first made to jet grout GMENT-12 and U.S. Grout with the 3-mm nozzles (two nozzles placed 180 degrees apart on the drill stem), and it was found that the system could not be pressurized with the high-pressure pump higher than 200 bar (3,000 psi) for either grout.

4.4.1.1 GMENT-12/U.S. Grout. For GMENT-12, use of a 2.4-mm nozzle resulted in achieving the desired pressure of 400 bar (6,000 psi), and a column was created with no grout returns. Based on preliminary calculations, the injection parameters included 5.1 s/step with a 5 cm step and 2 revolutions per step. Upon excavation following a 3-day cure, a cohesive column was revealed and removed in one cohesive piece using a standard backhoe. The measured dimensions of the column were 109 cm (43 in.) long and approximately cylindrical shaped, with an outside diameter averaging 63.5 cm (25 in.). With great difficulty, the column was broken in two pieces by dropping the bucket from a height of 0.61 m (2 ft) over 10 times. The column appeared to consist of mostly pure grout well mixed with soil, with some visible soil inclusions as shown in Figure 16. Some 0.5-cm diameter voids were found in the monolith (also shown in Figure 16). These pours were most likely from void redistribution in the soil and/or entrained air during grouting.

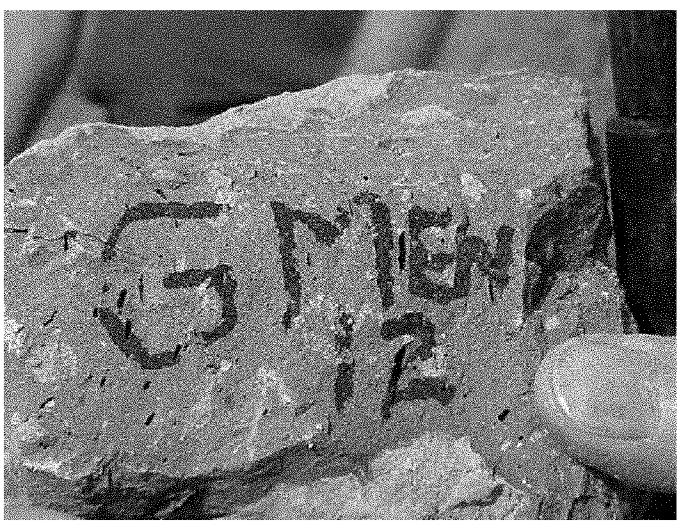

Figure 16. GMENT-12 mixtures of soil and grout.

A total of 208 L (55 gal) of grout were used to make the column at a step time of 5.1s which gives an injection rate of 1.89 L/cm (15.3 gal/ft). The volume of the column represented about 91 gal and the injected grout was 208 L (55 gal) with no returns resulting in 60% grout void filling which means the INEEL like soils were very dry (less than 10 wt% moisture) or the soils were only slightly compacted. This compares to estimates of a total void of 60% for the buried waste in the SDA.

A similar evaluation was made for the U.S. Grout material in that the 3-mm nozzle also could not support the 400 bar (6,000 psi) grouting pressure thus the 2.4-mm nozzle was recommended. The dimension of the resultant column was similar to that created for the GMENT-12 and was 61 cm (24 in.) in diameter and 1.2 m (4 ft) high.

4.4.2 Creating a Triplex Column Using the Thrust Block

A series of three connected holes were grouted in a 50 cm (20 in.) triangular pitch for each of the three grouts. For each of the cases, the grout was prepared in a vortex mixing system that allowed mixing at least enough grout for a single column such that the grouting was essentially performed as one operation with no curing of the grout between grout holes. Grouting was performed using a thrust block to collect any grout returns. The first grout injected was the GMENT-12 followed by the U.S. Grout and finally the TECT HG. Table 24 summarizes the volume of grout injected in forming the grout columns. What follows is a description of the grouting operation and data obtained during grouting.

Table 24. Volume (gal) of grout injected during the implementability tests (3.78 L/gal).

Grout Type	Hole number	Grout Flow (Jean Lutz Flow Meter)	Total Grout Injected
GMENT-12	1	93	360
	2	139	
	3	128	
U.S. Grout	1	156	260
	2	104	
TECT HG	1	90	331
	2	158	
	3	83	

4.4.2.1 GMENT-12

A triplex column (completely interconnected set of three individually emplaced columns) was successfully created using the GMENT-12 grout. The grouting parameters were based on the initial nozzle tests and were set at 5.1s/step, 2 revolutions per step and a 5 cm step size with grouting pressure at 400 bar (6,000 psi) for all three positions grouted. Three gallons of water were mixed with each 27.2 kg (60 lbm) bag of dry ingredients. During grouting, no grout returns to the surface of the thrust block were observed; however, when grouting the final hole 11.3-18.9 L (3-5 gal) of grout returns flowed from the side of the thrust block as the final inches of the third hole were grouted. Table 24 summarizes the volume of grout injected in forming the columns using the Jean Lutz metering system and shows that a total of 1,360 L (360 gal) of grout were injected with no returns to the surface of the thrust block (i.e., no overflow). This equated to about 1.8 L/cm (15 gal/ft) delivered to each hole during grouting.

4.4.2.2 U.S. Grout

Only two holes of the planned triplex column were grouted because excessive grout returns to the surface of the thrust block during the grouting of the second hole precluded grouting any further. The parameters for grouting the U.S. Grout were 5.5 s per step, 2.4-mm nozzle size, 5 cm step size, and 400 bar (6,000 psi) pressure at the high-pressure pump. A mud balance measurement was taken on the grout at 1.57 kg/L (13.1 lbm/gal), which agrees with the density measurements in the bench study. The U.S. Grout was found to be easy to mix. There was a reduction in lumps of solid material that had to be mixed relative to mixing the GMENT-12 grout and about 90 L (24 gal) of water were used in mixing. With the U.S. Grout there was an initial plugging of a nozzle. This plugging was not attributed to the grout rather, it was the first grout hole of the day and debris in the lines could have accounted for the plugging. A total of 982 L (260 gal) of grout were delivered in the two holes during the grouting operation which essentially filled the thrust block with returns. In fact, the first hole had 589 L (156 gal) of grout in the 2.4 m (8 ft) column grouted and in the second hole only 393 L (104 gal) was injected [the column was between 1.2–1.5 m (4-5 ft) deep] when grouting was suspended because of the excessive return. Because of this complete filling of the thrust block with grout returns, it was decided to not grout the third hole. Further grouting was impossible because grout returns had no void under the thrust block to fill therefore, continued grouting would have caused massive spillage out the top the thrust block. The relatively low density U.S. Grout simply did not impart enough kinetic energy to the soil and simply could not overcome the resistance of the soil and copious grout product came to the surface as a grout return.

4.4.2.3 TECT HG

TECT HG was successfully injected in a total of 5 positions (two limited length-field trials and 3 holes using the thrust block). Initially, it was desired to inject a similar volume of grout for the TECT HG as the GMENT-12 so that a valid comparison could be made relative to column development in conditions of similar soil voids. To set these desired parameters, and to maximize the availability of grout material, the field trails only involved two-foot high columns in an iterative approach. These field trials were also necessary because the TECT HG grout is of higher density than the GMENT grout (specific gravity of 2.16 g/cm^3 for TECT HG and 1.6g/cm^3 for GMENT-12). The 3-mm nozzle was used and the mud balance reading on the TECT HG grout was 17.5 lbm/gal [2.1 g/cm^3] again in agreement with the bench studies. In addition, the initial field trial was at 400 bar (6,000 psi), 5 cm/step and 5.0 s/step. In 0.35 m (1.15 ft) of column, 93 L (24.8 gal) of grout were injected or 2.6 L/cm (21.56 gal/ft), which was much higher than the average of 1.8 L/cm (15 gal/ft) injected in the GMENT-12 triplex columns. In the second field trial the time on a step was adjusted to 3.5 s/step and the result was 65 L (17.2 gal) for 0.35 m (1.15 ft) column or about 1.8 L/cm (15 gal/ft). Therefore, the first 2.4 m (8 ft) column of the triplex under the thrust block was grouted at 3.5 s/step with the result that 340 L (90 gal) of grout was injected for 1.38 L/cm (11.2 gal/ft) which was short of the goal of 1.8 L/cm (15 gal/ft). Therefore, using proportioning, the next hole was grouted using 4.5s/step with the result of 597 L (158 gal) of grout injected or 2.44 L/cm (19.7 gal/ft). This action overshot the desired 1.8 L/cm (15 gal/ft) so the last hole was grouted at 4s/step with a total of 317 L (83.75 gal) in a 1.7 m (5.7 ft) hole [the system ran out of grout before the total length of 2.4 m (8 ft) could be grouted] which resulted in 1.8 L (14.7 gal/ft), which was close to the desired 1.8 L/cm (15 gal/ft) average. Overall, in the three holes the total amount of grout injected was within 10% of that injected into the GMENT-12 pit. During grouting of these three holes under the thrust block, there were copious returns of grout pouring out the field trial holes that were located just off the side of the thrust block indicating communication between holes. Following grouting, a 7 cm (2.75 in.) polyethylene rod was easily hand inserted into one of the grout holes to evaluate this technique of creating a test penetration for hydraulic conductivity measurements during the field testing.

Possible explanations for this unpredictable behavior in grout delivery include (a) a random variation in step time or (b) millisecond periods in which the back pressure offered by the waste caused a millisecond reduction in flow not seen by the pressure/flow measurement systems. The step time was measured repeatedly during the implementability testing and was found to be fairly easy to set. However, it is possible when ranging out 2.4 m (8 ft) of hole there are approximately 50 steps and the step time could actually slip as it goes through the 50 steps. As far as the loss-of-pressure theory, it is unlikely that the response of the Jean Lutz would not pickup the millisecond oscillation in flow. Specifically, the pressure should have shown an oscillatory nature to account for each pressure variation.

The problem of predicting grout flow based on a given set of parameters from one hole to another was also evident in past grouting campaigns (Loomis 1997). The main parameters that is varied is the dwell time or time in a step. Table 25 summarizes the data discussed above with a common 400 bar (6,000 psi) pressure, 2 revolutions per step and a 5 cm step size:

Table 25. Gallons of grout per feet at various dwell times.

Dwell Time(s)	gal/ft (multiply by 0.12 to get L/cm)
5	21.56 gal/ft
3.5s	15 gal/ft
3.5s	11.2 gal/ft
4.5s	19.7 gal/ft
4 s	14.7 gal/ft

Examining the table at 4s dwell time 1.8 L/cm (14.7 gal/ft) were delivered which is the same as one of the 3.5s dwell time cases. In addition, for different 3.5s dwell times, there was a variation in grout delivered from 1.3 L/cm (11.2 gal/ft) to 1.8 L/cm (15 gal/ft). What is needed to resolve this issue is to perform separate effects flow tests in which grout is injected in air while measuring the grout flow for various dwell times. If this test shows consistent results with increasing integrated grout flow after increasing dwell time, then the variable-pressure idea has some merit. If the back pressure idea has merit, then during operations, the total delivered grout delivery rate for various regions of the pit will have to continuously be adjusted by varying the dwell time repeatedly.

4.4.3 Observation of Halliburton Reading Versus Jean Lutz Reading

During past testing performed in simulated waste (Loomis 97), the Halliburton flow meter was used to measure the volumetric flow rate of grout during grouting of Type-H cement, TECT, and molten paraffin. For the pits grouted with TECT and to a certain extent, the Type-H cement, the amount of grout injected did not match the estimated void volume of 60-70% voids. Both pits were injected with an amount of grout far in excess of these available voids. For the TECT pit, the amount of grout injected was 4,222 L (1,117 gal) in only 11 out of a total possible 18 holes. The total volume of the pit was only 6,104 L (1,615 gal) which means the amount of grout injected was 70% of the total pit volume. On a basis of amount injected per the amount of surface area covered (11/18 of the total surface area), the amount injected is 113% of the volume of that part of the pit. It is also noted that upon excavation, the total pit did not contain grout so the argument that the grout simply flowed to voids in other ungrouted parts of the pit is not valid. For the pit grouted with Type-H cement, a total of 5,428 L (1,436 gal) were injected into 18 holes covering the same volume as the TECT pit [6,104 L (1,615 gal pit)] which accounts for an 88% void filling in yet the amount of voids was expected to be only 60-70%. Because of these data, it was suspected at the time that the Halliburton flow meter was for some unknown reason artificially reading high by as much as 20-30%.

With this background, the implementability testing used both the Jean Lutz and Halliburton flow meters in an attempt to reconcile the differences seen in the 1997 work for all types of grouts. Table 26 below summarizes the data.

Examining the data in Table 26 the average Halliburton/Jean Lutz ratio for GMENT-12 = 1.12, U.S. Grout = 1.13, and TECT HG = 1.17. If the Jean Lutz is considered the standard then the Halliburton measures grout flow approximately 14% high. This argument is in agreement with the data obtained in 1997 in the pit grouted with type-H cement in which it was concluded that 88% of the total excavated pit volume was grouted in yet the expected void volume was 60-70%. No conclusions can be made relative to the data taken relative to the pit grouted with TECT in 1997 because only a portion (11/18th) of the pit was grouted. Therefore as a backup measurement technique, under high pressure conditions, it is concluded that the Halliburton system consistently gives a 14% high reading for a variety of grout types. This is exactly why the Jean Lutz system was chosen in that it measures strokes of the pump independent of fluid type.

Table 26. Volumetric flow of grout during the implementability testing (3.78 L/gal).

Grout Type	Halliburton Reading (total gal)	Jean Lutz Reading (total gal)
GMENT-12	105	93
	157	139
	144	128
U.S. Grout	176	156
	120	104
TECT HG	106	90
	186	158
	98	83

4.4.4 Special Drill Steel Drain Test

During grouting with the TECT HG grout the high-pressure pump was turned off, and the drill steel was raised to observe how long it took to drain the drill steel of grout via the nozzles. For several holes it took as low as 1min and as much as 5min to drain the grout material in the drill stem. The elapsed time of 5 min was recommended for the length of time to leave the sub assembly under the thrust block prior to bringing it above the thrust block during the field test. This action would ensure that the double bag around the sub-nozzle assembly (as a contamination control strategy) would not fill during the field testing and effect the operation of the drill string shroud assembly.

4.4.5 Ease of Mixing of Grout and Clean-out

Following grouting of the three types of grout, the grouting contractor was interviewed as to ease of use of the grouts to determine which of the three grouts (TECT HG, GMENT-12, U.S. Grout) was the easiest to mix and, following grouting, to clean-out. During grouting, the down time to clean out plugged nozzles was basically the same for all grouts. In only one case did a nozzle plug-just before the field trial for the TECT HG holes. This plugging was due to debris in the grout not an inherent problem with the TECT HG grout. The grouting contractor claimed that U.S. Grout mixes easier than GMENT-12 and TECT HG is the hardest to mix because of the required liquid component. In addition,GMENT-12 is rated medium difficult to mix with minor clods that have to be broken-up during mixing. GMENT-12 with an all dry product is easier than TECT HG. When mixing U.S. Grout, superplasticizer must be put in very soon to allow mixing.

During clean-out the grouting contractor evaluated (on a scale of 1-10 with 10 the most difficult) the degree of difficulty for the clean out process. The results are listed below:

- TECT HG is hardest by far (some filter caking)-8

- GMENT-12 is second hardest with no filter caking-4
- U.S. Grout displayed some filter caking-4.

These qualitative observations from the grouting contractor apply to using the small batch vortex mixer; however, even in a large batch plant mode the comments are still valid (approximately 1 yd^3).

In summary, U.S. Grout is easiest to mix followed by GMENT-12 and the hardest was TECT HG. TECT HG is by far the most difficult to clean out with GMENT-12 and U.S. Grout similar but fairly easy to clean out.

4.4.6 Grout Returns Under Thrust Block

The amount of grout returns under the thrust block were measured by filling the remaining void in the thrust block with fluid and subtracting that value from the calculated volume of the total void under the thrust block. The lower the measured return, the less likely that contaminated grout returns will escape the thrust block during a hot application. A special mixture of bentonite (Wyoming Bentonite-Billings Montana) and water was prepared in the first vortex mixing system. The idea was to use a bentonite slurry to eliminate errors in measuring the volume under the block in that the slurry would seal any leakage paths under the block. A special test block was created in the local sand and the bentonite slurry mix effectively sealed the sand from slurry flow using a ratio of about 5.4 kg (12 lbm) bentonite per 151 L (40 gal) of water. Using the flow meter on the vortex mixer, the slurry was pumped under low pressure into each of the thrust blocks. Because all of the holes in the thrust block used for U.S. Grout were sealed with grout returns (indicating a completely full thrust block) it was impossible to fill the U.S. Grout block. For the TECT HG thrust block a total of 94.5 L (25 gal) of slurry was placed in the thrust block and for; the GMENT-12 thrust block a total of 267 L (70.8 gal) of slurry was placed. Therefore, for the TECT HG grout, there were a total of 449 L (119 gal) minus 94 L (25 gal) or 355 L (94 gal) of grout returns and for GMENT-12, a total of 449 L (119 gal) minus 267 L (70.8 gal) or 181 L (48 gal) of returns.

In summary, U.S. Grout had the most grout returns at 449 L (119 gal) of grout returns even with only 2 holes grouted with a total of 982 L (260 gal) injected meaning 45% of what was injected came up to the surface. Next , TECT HG had the second most grout returns at 355 L (94 gal) with a total of 1,251 L (331 gal) injected meaning a 28% volumetric return, and finally, GMENT-12 had the least grout returns at 181 L (48 gal) with 1360 L (360 gal) injected for a 13% return. Comparing the amount of grout returns to the amount of grout injected in each of the blocks shows that GMENT-12 clearly had the best results of the three grouts tested as shown in Table 27.

Table 27. Comparison of grout take and grout returns (3.78 L/gal).

Grout Type	Grout Take (gal)/#holes	Grout Returns
TECT HG	332/3	94 plus 30 gal blowout = 124
GMENT-12	361/3	48
U.S. Grout	260/2	119

Since only two grouted holes filled the thrust block for the U.S. Grout for a loose soil condition, it is anticipated that when grouting the soil surrounding the pit during the field test that the U.S. Grout would produce too much return to allow a safe operation.